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(54) Resolution enhancement by synthesis of scan signals

(57) Digital image data of high resolution are obtained by synthesis of the scanning signals of two scanners, which scan an original document with mutually different lower resolutions.

The synthesis comprises transforming the scan signals of the first scanner into a first spectrum and transforming the scan signals of the second scanner into a second spectrum, superposing in predetermined manner versions of the first and second spectrum shifted over the spectral axis, and deriving a third spectrum from the result thereof. Retransformation of the third spectrum finally gives the required digital image data of high resolution.

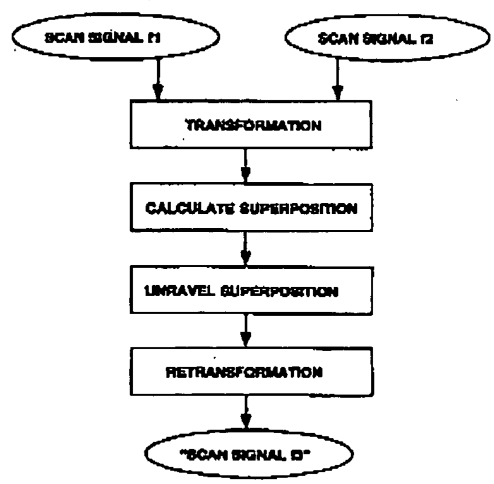

FIG. 4

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Description

[0001] The invention relates to a method and apparatus for generating digital image data, relating to an image, as is the case, for example, in a digital copying machine or in a free-standing scanner apparatus.

[0002] In apparatus of this kind, a document having an image thereon is scanned by means of an electro-optical converter to generate digital image data which contain a grey value for each image element or pixel. This is usually done with a CCD array, on which a part of the document in the form of a line is projected by an optical imaging system. By moving either the document or the imaging system in a direction perpendicular to the said line part of the document, the document is scanned completely, line-by-line, in accordance with a usually rectangular raster of pixels.

[0003] The spatial density or resolution of the pixels is in practice of the order of some hundreds of pixels per inch, usually specified as "dpi" (= dots per inch).

[0004] For a good description of an image it is of course desirable that pixels should have a high spatial density. However, high-resolution systems are expensive, both because of the requirements relating to the CCD array and the requirements relating to the optical imaging system. There is therefore a demand for a scanner system which generates image data at high resolution and is yet constructed from simple and hence inexpensive components. The present invention meets this demand.

[0005] To this end, the method according to the invention comprises the following steps:

1) generating first digital image data by scanning the said image with a scanner having a first resolution f1;
2) generating second digital image data by scanning the said image with a second scanner having a second resolution f2 higher than f1;
3) and combining the said first and second digital image data to form third digital image data, which describe the said image with a third resolution f3 which is higher than f1 and higher than f2.

[0006] According to one embodiment, step 3) comprises the following sub-steps:

a) transforming the said first digital image data into a first spectrum, and transforming the said second digital image data into a second spectrum, which spectra have an amplitude on a spectral axis;
b) superposing in a predetermined manner versions of the first and second spectrum shifted over the spectral axis, to give a first combination;
c) deriving a third spectrum from the first combination;
d) and re-transforming the third spectrum, the result being interpreted as the third digital image data.

[0007] The invention is based on combining the image data of two scanners, each of which has a relatively low resolution different from the other, to give image data of a higher resolution. This combination is possible in the frequency domain. The digital image data are therefore first transformed thereto with a Fourier transform, whereafter they are processed further. Alternatively, it is possible to subject the image data to a cosine transform and carry out the combination in the cosine domain.

[0008] The said resolutions are preferably so selected that

$$f3 = f1 + f2 - G(f1,f2)$$

where G(a,b) is the highest common divisor of a and b. On the basis of theoretical considerations, this value of f3 is the highest frequency at which the results of the method still form a reliable estimate of the original image, i.e., still correspond to the original image, if the latter were scanned at the resolution f3. There is therefore no point in making f3 higher, because it does not yield any more information. On the other hand, it is also undesirable to make f3 lower, because then the information present in the image data is not used to maximum effect.

[0009] As a marginal condition for the values of f1 and f2, their ratio must be a rational ratio because it is only in that case that the theory on which the processing of the digital image data from the scanner is based is valid. However, this does not form any limitation, because this is always the case as a result of the discrete form of the scanners.

[0010] It should be noted that operations in the frequency domain on image data of two scanners each having a resolution different from the other is known per se. These operations relate mostly to filtering image data in order to remove disturbing elements from the digitised image.

[0011] In this connection, US-A-5 121 445 describes a method aimed at removing moiré patterns. Patterns of this kind occur when a rastered image is scanned with a scanner, due to the fact that the raster frequency of the image interferes with the scanning frequency (resolution) of the scanner. The interference causes sidebands on either side of the spectrum of the original non-rastered image, in the frequency domain. Also, the entire spectrum, including the sidebands, is periodically repeated as a result of the discrete scanning by the scanner. The said sidebands contain information on

both the rastering and the scanning. The known method comprises eliminating the side bands as far as possible by comparing the spectra of the image data from the two scanners, so that the original non-rastered image can be reconstructed. Thus this method not only removes the moire but also the raster. Effectively, therefore, information present in the scanned image is destroyed. The precise object of the present invention is to retain as far as possible all the information in the scanned image.

[0012] The invention will now be explained with reference to the following Figures, in which like references refer to like elements. The exemplified embodiment in this explanation is, however, only one example of one possible implementation. It will be clear to the skilled man that other embodiments of the invention are possible within the scope of the claims.

[0013] In the drawings:

Fig. 1 is a diagram showing the principle of the scanner apparatus according to the invention.
Fig. 2 is a block schematic of the apparatus according to the invention.
Fig. 3A is a simplified spectrum of an original image.
Fig. 3B is a spectrum of a scan signal of an image.
Fig. 4 is a diagrammatic representation of the process of reconstructing a high-resolution signal from the two lower-resolution scan signals in accordance with the invention.
Figs. 5A - F are a visualisation of the operations on the spectra during the reconstruction.

[0014] Fig. 1 is a sketch showing the principle of a scanner according to the invention. An original document 1 is transported in a direction 2 at a uniform speed. A lens 3 images the document on two CCD arrays 4 and 5, which scan a line area, perpendicular to the direction of transport 2, of the document, signals being generated in accordance with the grey values of image parts or pixels. These signals are converted to digital image data by means of A/D converters. Since the document is transported along the imaging system, the entire document is scanned line-by-line.

[0015] Generally, a combination of a CCD array and a lens is also termed a "camera". The scanner device of Fig. 1 thus comprises two cameras.

[0016] Array 4 scans the document with a resolution f1 and array 5 does so with a resolution f2, which is different from f1. This can be effected by using CCD arrays having different CCD density, and also by making the imaging system (the lens) different for the arrays, so that one array scans the document with a different enlargement from the other.

[0017] Instead of the lens in Fig. 1, it is also possible to use a selfoc lens array (an array of imaging optical fibres).

[0018] It is also possible to scan the document twice with different magnification, using one camera having variable magnification, and to store the signals of the two scans in a memory. The signals with different resolution are then not generated simultaneously, but can be delivered in synchronism finally by reading out of the memory simultaneously or semi-simultaneously the signals corresponding to the same line position.

[0019] Fig. 2 is a block schematic of the apparatus according to the invention in the embodiment of Fig. 1. The CCD arrays 4 and 5 are each connected to an A/D converter 11, 12 respectively, to convert their analogue signals into digital image data. The A/D converter 11 is connected to the delay device 13 for synchronising the image data, so that the image data delivered in the two channels relate to the same linear area on the scanned document. The delay device 13 is connected to a DFT module 14 and the A/D converter 12 is connected to a DFT module 15. A DFT module performs a discrete Fourier transformation on the image data. The DFT modules are each connected to a synthesis module 16. This is intended to combine the transformed image data from the two channels into transformed image data having a higher resolution f3 in the frequency domain. The operation of the synthesis module will be described hereinafter. The synthesis module 16 is in turn connected to an inverse DFT module 17 for transforming the data from the synthesis module into digital image data having the higher resolution f3.

[0020] The apparatus described here can be constructed as an independent scanner device for scanning documents and in so doing generating digital image data, which are then delivered via an electrical connection to, for example, a workstation or computer. The apparatus can also form part of a digital copying apparatus, in which the scanner signals are converted to control signals for a printing apparatus, whereby the latter prints a copy of the document on an image support, such as a sheet of paper. The structural elements required for the construction as shown in Fig. 1, although not described above, are generally known to the skilled man.

[0021] Before discussing the procedure in processing two image signals of spatial frequencies f1 and f2 respectively, to form an image signal of spatial frequency f3, reference will first be made to Figs. 3A and B, which show the effect of scanning on the image signal.

[0022] The basis taken in the following will be an original image, the spatial progress of the image information of which will be designated the "original signal h". The spectrum of "h" will be designated "H".

[0023] Fig. 3A shows a (simplified) spectrum (H) 21 of the original image. When this image is scanned with a spatial frequency fa, a scan signal is generated with a spectrum as shown in Fig. 3B. This spectrum contains the original spectrum 21 and periodic repetitions 22 of this spectrum on the multiples of the scanning frequency fa. When the scanning

frequency fa is sufficiently high compared with the extent of the original spectrum, the original image signal can be recovered faultlessly from the spectrum of the scanning signal. If the bandwidth of h is greater than fa/2, then the periodic repetitions of the original spectrum will overlap one another and distortion will occur so that the original image signal h can no longer be recovered faultlessly. This is known as the Nyquist theorem in signal theory.

[0024] The spectrum H_a of an original signal h scanned at a frequency fa can now be described as:

$$H_a = \sum_{k=-\infty}^{\infty} T^{kfa} H$$

wherein H is the spectrum of h and
T^s is a shift operator defined as: $(T^s f)(t)=f(t-s)$,
where f is any function.

[0025] This formula is the mathematical representation of what is shown in Fig. 3B.

[0026] The process of reconstruction of an approximation of the original signal h from the two scanning signals or, more generally, of the processing of two image signals of frequencies f1 and f2 respectively, to form an image signal of frequency f3, is shown in Fig. 4. It progresses in four steps. In the first step, the spectra of the scanning signals are calculated by means of a Fourier transform. In the second step a superposition of the spectra of the scanning signals is calculated. In the third step, the result of the superposition is unravelled so that (by approximation) the spectrum H of the original signal remains. The (approximated) original signal is derived from this in the fourth step by inverse Fourier transformation, so that it would appear as if scanning was carried out at the increased frequency f3.

[0027] This procedure will now be explained by reference to a numerical example. The general case will be discussed hereinafter.

[0028] Two scanning frequencies f1 = 200 dpi and f2 = 300 dpi are used for this example.

[0029] The various steps of the process as described with reference to Fig. 4 will now be described in greater detail.

First step

[0030] Fig. 5A shows the spectrum H of an original image h obtained by subjecting the latter to a Fourier transform. Figs. 5B and 5C respectively show the spectra H_1 and H_2 respectively of the two scanning signals associated with the scanning frequencies f1 and f2 respectively. It will be clear that these spectra are not suitable for reconstructing the original signal h faultlessly therefrom, due to the overlapping of the periodic repetitions.

Second step

For the purpose of explanation, an auxiliary frequency fx will first be introduced, which is defined as:
fx = K(f1, f2), where K denotes the lowest common multiple.

[0031] In the example, therefore, fx = 600 dpi.

[0032] The following superposition s is selected for the example described:

$$s = T^{-100} H_1 - H_2$$

[0033] This choice is based on the following considerations. Let us assume that the original signal h was scanned at a frequency fx, i.e. 600 dpi, then the spectrum of the scanning signal was:

$$H_x = \sum_k T^{600K} H$$

[0034] It will readily be seen that

$$H_1=(1+T^{200}+T^{400})H_x$$

$$H_2=(1+T^{300})H_x$$

[0035] In order to avoid overlapping as much as possible, there is selected for the superposition a combination in

which the shift differences are kept as small as possible. A good choice therefore is the above-mentioned combination, because in that case:

$$T^{-100}H_1 - H_2 = (T^{-100} - 1 + T^{100})H_x$$

[0036] One period is now cut out of the result s of the superposition by making equal to zero all the spectra values outside (-fx/2, fx/2), in this example: (-300, 300). The result of this is shown in Fig. 5D.

[0037] When the bandwidth of the original signal h is less than 200 dpi, generally (f1 + f2 - G(f1, f2))/2, where G denotes the largest common divisor, this equation also applies when H_x is replaced by H, because then there is no overlapping of spectra. In the case of larger bandwidths the resulting signal is distorted.

Third step

The resulting spectrum is then unravelled by again subjecting it to a combined shift operator. A good choice for this operator appears to be:

$$(T^{-200} + T^{-100} - T^{100} - T^{200})$$

The result of this is shown in Fig. 5E.

[0038] A cut-out is made from this spectrum between (-fx, 0), in this example (-600, 0), whereafter a last translation $T^{fx/2}$, in this example T^{300}, delivers an approximated spectrum H' of the original signal h. This is shown in Fig. 5F.

Fourth step

An estimate of the original signal h can then be calculated from the spectrum H' using an inverse Fourier transform. To have the signal available at the required frequency f3 after transformation, the spectrum H' is first periodically repeated with period f3 by using the operator

$$\sum_{k=-\infty}^{\infty} T^{k f3}$$

and then subjected to inverse Fourier transformation.

In practice, this step is carried out in one operation by using a discrete inverse Fourier transform with the correct period.

[0039] The process has been explained as an example hereinbefore for the case of f1 = 200 dpi, f2 = 300 dpi.

The process will now be described in general form hereinafter.

The scanning frequencies should be so selected that f1/f2 is a rational ratio (this is always the case in practice due to the construction of the scanner with discrete CCD arrays). There are then natural numbers a and b, for which:

$$f1 = G(f1,f2) \, . \, a$$

$$f2 = G(f1,f2) \, . \, b$$

$$fx = b \, . \, f1 = a \, . \, f2$$

where G(f1, f2) is the largest common divisor of f1 and f2.

First step

The first step comprises Fourier transformation of the signals obtained by scanning with scanning frequency f1 and f2 respectively, and is of course the same as the first step described above in the exemplified process.

Second step

We then define an operator $S = T^{G(f1,f2)}$
and operators P_a and P_b, for which:

$$P_a = (1+S^a+S^{2a}+...+S^{(b-1)a})$$

$$P_b = (1+S^b+S^{2b}+...+S^{(a-1)b})$$

then:

$$H_1 = P_a H_3$$

$$H_2 = P_b H_3$$

There are now operators A and B, for which:

$$A \,.\, P_a + B \,.\, P_b = G(P_a,P_b)$$

$G(P_a,P_b)$ is the largest common divisor of the operators P_a and P_b, contained as polynomials in S.

[0040] A, B and $G(P_a,P_b)$ can be found by using the Euclidean algorithm known in mathematics. In the above exemplified case, this would give:

$$G(P_a,P_b)=1-S^1+S^3-S^4+S^5-S^7+S^8$$

$$A = -S^1$$

$$B = 1 + S^3$$

The following is now taken as superposition s (again for the general case):

$$s = S^{-(a-1)(b-2)/2}(A.H_1+B.H_2)$$

One period is now cut out of the result s of the superposition by making all the spectrum values outside (-fx/2, fx/2) equal to zero.

If the bandwidth of the original signal h is limited within the value (f1+f2-G(f1,f2))/2 , then the following also applies:

$$s=S^{-(a-1)(b-1)/2}G(P_a,P_b).H$$

Third step

The resulting spectrum is then unravelled by subjecting it to the following operator:

$$S^{(1-a-b)/2}(1-S^1)(1+S^1+...+S^{a-1})(1+S^1+...+S^{b-1})$$

[0041] From this spectrum a cut-out is made between (-fx,0), whereafter a last translation $T^{fx/2}$ gives an approximated spectrum H' of the original signal h.

[0042] If the bandwidth of the original signal h is limited within the value (f1+f2-G(f1,f2))/2 , then the unravelling yields:

$$H'=(S^{-fx/2}-S^{fx/2})H$$

so that H and h are exactly reconstructed.

Fourth step

This is again the same as the fourth step described above. This completes the reconstruction.

[0043] By means of the above description it is possible, using two cameras having relatively low resolutions f1 and f2 which differ from one another, to construct a scanner device which can deliver digital image signals having a relatively high frequency f3. The latter image signals are then synthesised from the signals of the two cameras using the above-described method.

[0044] It should be noted that the synthesised signal has a frequency content defined by f3 = (f1+f2-G(f1,f2)) . Selecting a value for f3 higher than (f1+f2-G(f1,f2)) does not yield a sharper image than that for the value mentioned here.

[0045] In the example use was made of (discrete) Fourier transform. However, use can also be made of other orthog-

onal transformations, such as, for example, (discrete) cosine transform. The method is not changed as a result, although the operators used may differ. It is within the scope of the skilled man to adapt the operators for other transformations, the skilled man in this case having a wide knowledge of both signal theory and mathematics.

[0046] The scan signals can also be generated with two-dimensional CCD arrays of different resolutions, or one or two identical two-dimensional arrays with different magnification optics. The image signals can be synthesised, similarly to the above-described method, by a suitable adaptation of the data processing, either by splitting the two-dimensional algorithm into one-dimensional operations, or by adapting the theory for the two-dimensional case.

Claims

1. A method of generating digital image data relating to an image, comprising

   generating first digital image data by scanning the said image with a first scanner having a first resolution f1;

   generating second digital image data by scanning the said image with a second scanner having a second resolution f2 higher than f1;

   and combining the said first and second digital image data to form third digital image data, which describe the said image with a third resolution f3 which is higher than f1 and higher than f2.

2. A method according to claim 1, wherein the combination of the said first and second digital image data comprises:

   a) transforming the said first digital image data into a first spectrum, and transforming the said second digital image data into a second spectrum, which spectra have an amplitude on a spectral axis;

   b) superposing in a predetermined manner versions of the first and second spectrum shifted over the spectral axis, to give a first combination;

   c) deriving a third spectrum from the first combination;

   d) and re-transforming the third spectrum, the result being interpreted as the third digital image data.

3. A method according to claim 2, wherein an orthogonal transform is used in step a).

4. A method according to claim 3, wherein the transform is a Fourier transformation.

5. A method according to claim 3, wherein the transform is a cosine transformation.

6. A method according to claim 2, wherein step c) comprises:

   c1) removing repetitions from the said first combination in such manner that one single period remains;

   c2) superposing copies of the said one single period, which copies are shifted over the spectral axis, to form a second combination;

   c3) making a cut-out from the said second combination, in such manner that one single spectrum remains; and

   c4) shifting the latter one single spectrum over the spectral axis over a distance determined in accordance with a predetermined criterion, in such manner that it comes to rest symmetrically on the spectral axis.

7. A method according to claim 6, wherein step c1) is carried out by making the amplitude of the combined spectrum equal to zero for frequency values less than -fx/2 and larger than fx/2, wherein fx is the lowest common multiple of f1 and f2.

8. A method according to claim 6, wherein step c3) is carried out by making the amplitude of the said second combination equal to zero for frequency values less than -fx and greater than zero, wherein fx is the lowest common multiple of f1 and f2.

9. A method according to claim 7, wherein step c4) is carried out by shifting said one single spectrum over a distance fx/2, wherein fx is the lowest common multiple of f1 and f2.

10. A method according to claim 1, wherein the said resolutions are so selected that

$$f3=f1 + f2 - G(f1,f2)$$

wherein G(a,b) is the highest common divisor of a and b.

11. A method according to claim 1, wherein by approximation f1 = 200 dpi, f = 300 dpi and f3 = 400 dpi.

12. A method according to claim 1, wherein by approximation f1 = 300 dpi, f = 400 dpi and f3 = 600 dpi.

13. Apparatus for generating digital image data relating to an image, comprising

means for scanning the said image, with a first resolution f1, and in so doing generating first digital image data;

means for scanning the said image, with a second resolution f2, and in so doing generating second digital image data, which second resolution f2 is higher than f1;

and means for combining the said first and second digital image data, relating to a same portion of the image, to give third digital image data, which describe the said image with a third resolution f3 higher than f1 and higher than f2.

14. Apparatus according to claim 13, wherein the means for scanning the image comprise a scanner constructed from an array of electro-optical converters and means for imaging at least a part of the image on the said array.

15. Apparatus according to claim 14, comprising two said scanners, one of which scans the image with the said resolution f1 and the other scans the image with the said resolution f2.

16. Apparatus according to claim 14, comprising a scanner provided with means for scanning an image with different resolutions,

in which apparatus the means for scanning the image utilise said scanner to generate the first and the second digital image data,

and which apparatus is also provided with a memory for intermediate storage of digital image data, connected to the means for scanning and to the means for combining the said first and second digital image data.

17. Apparatus according to claim 13, wherein the means for combining the said first and second digital image data comprise:

a) means for transforming said first digital image data into a first spectrum, and transforming said second digital image data into a second spectrum, which spectra have an amplitude on a spectral axis,

b) means for superposing in a predetermined manner versions of the first and second spectrum, shifted over the spectral axis, to give a first combination,

c) means for deriving a third spectrum from the first combination,

d) means for retransforming the third spectrum.

18. Apparatus according to claim 13, wherein by approximation f1 = 200 dpi, f = 300 dpi and f3 = 400 dpi.

19. Apparatus according to claim 13, wherein by approximation f1 = 300 dpi, f = 400 dpi and f3 = 600 dpi.

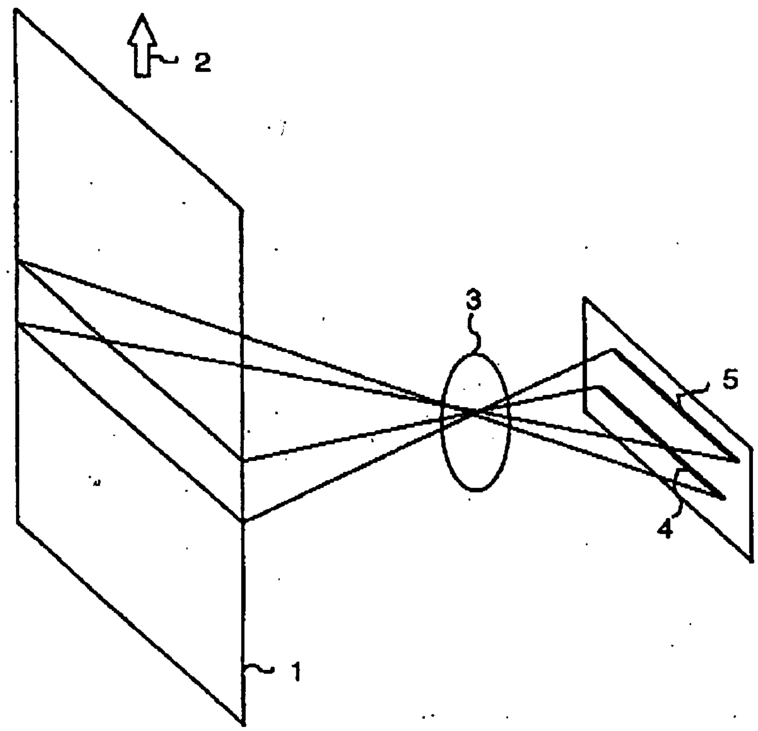

FIG. 1

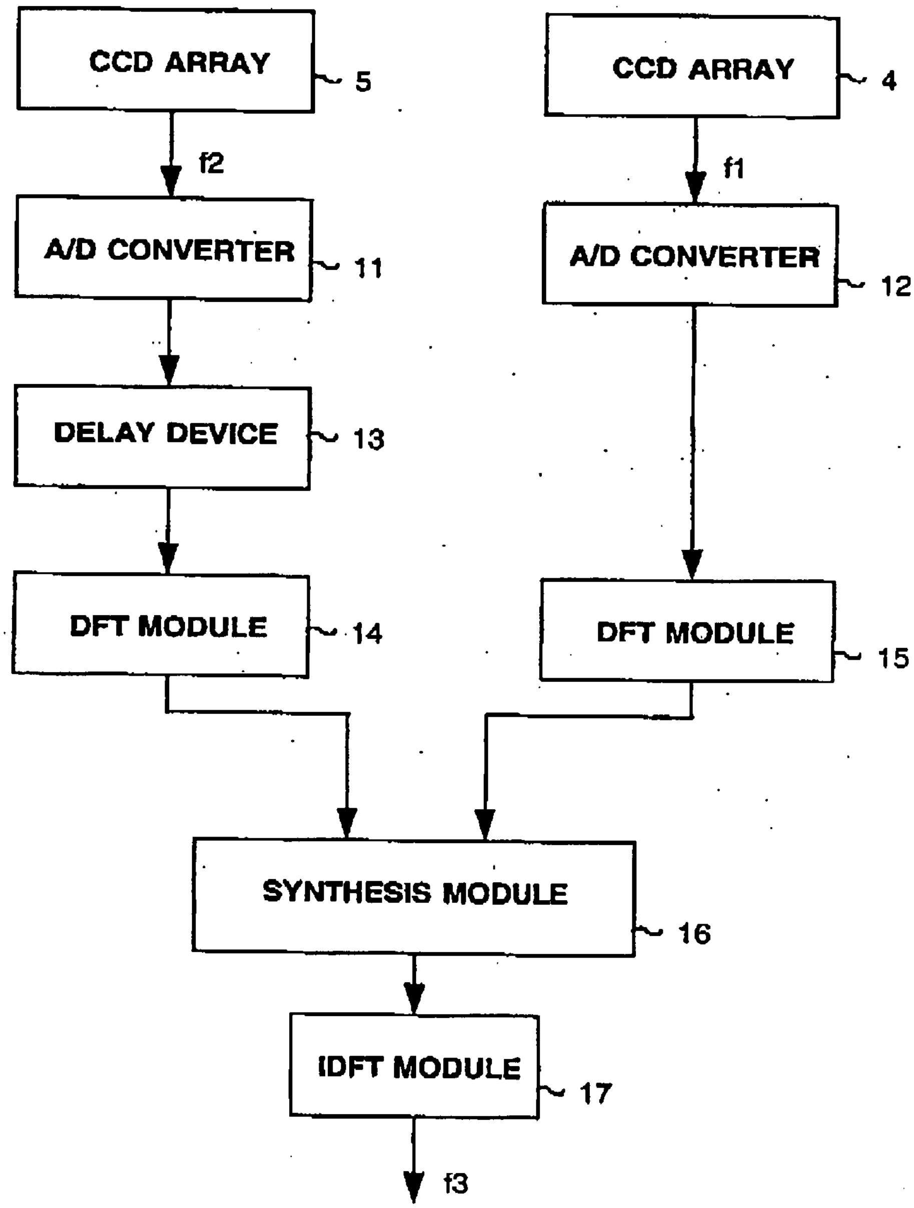
CCD ARRAY
5
CCD ARRAY
4
f2
f1
A/D CONVERTER
11
A/D CONVERTER
12
DELAY DEVICE
13
DFT MODULE
14
DFT MODULE
15
SYNTHESIS MODULE
16
IDFT MODULE
17
f3

FIG. 2

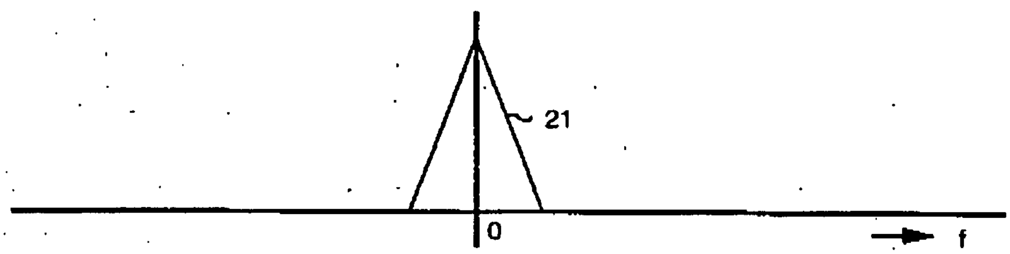

FIG. 3A

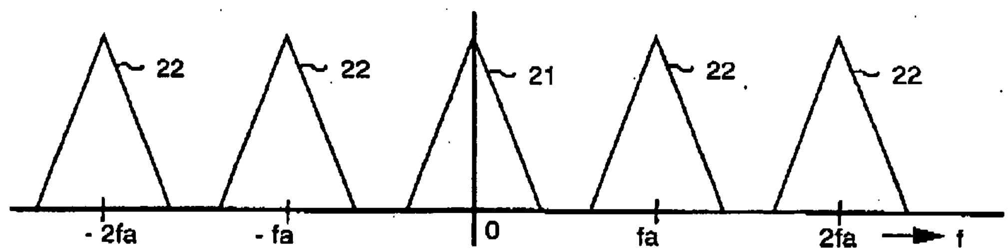

FIG. 3B

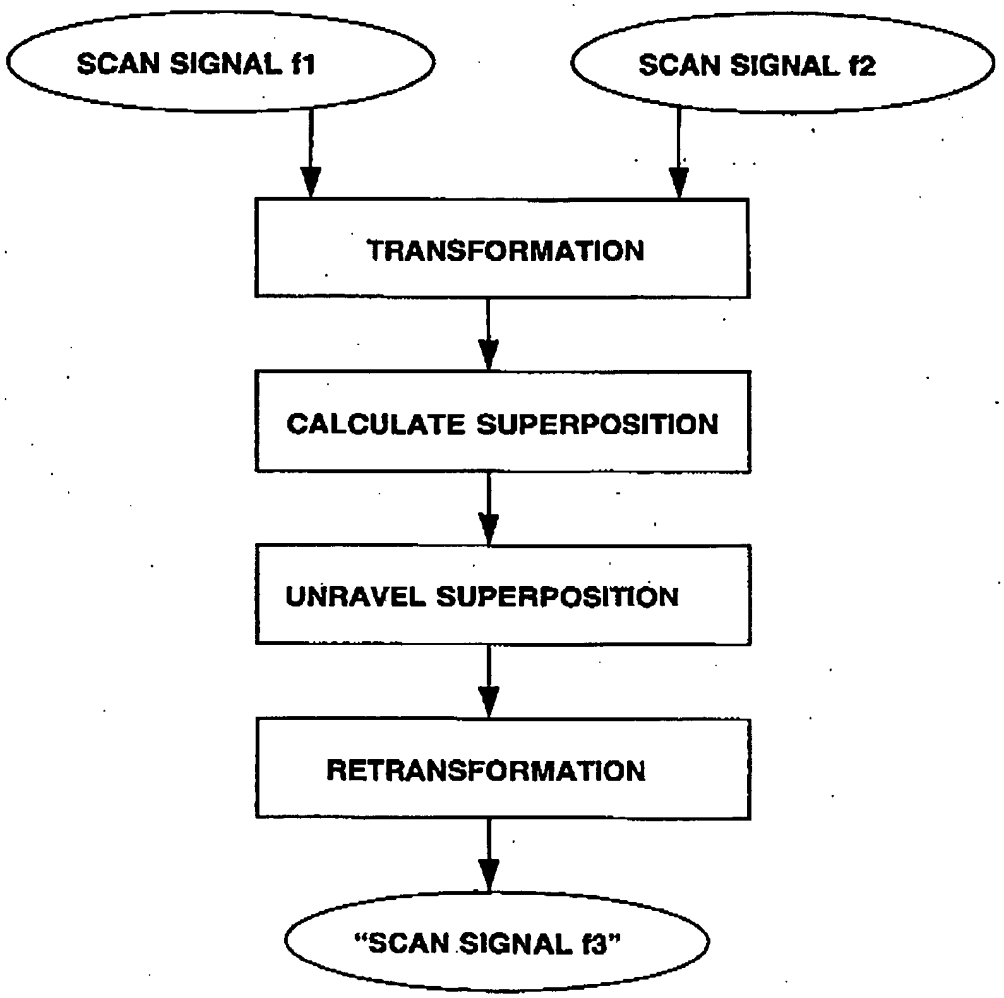
SCAN SIGNAL f1
SCAN SIGNAL f2
TRANSFORMATION
CALCULATE SUPERPOSITION
UNRAVEL SUPERPOSITION
RETRANSFORMATION
"SCAN SIGNAL f3"

FIG. 4

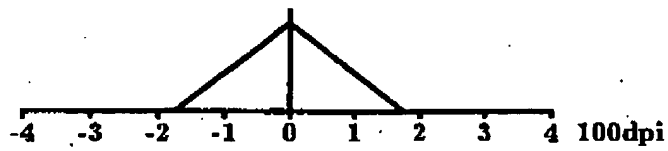

FIG. 5A

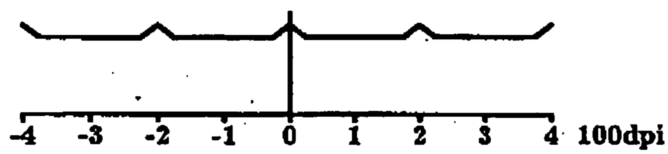

FIG. 5B

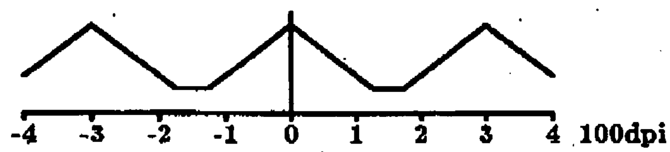

FIG. 5C

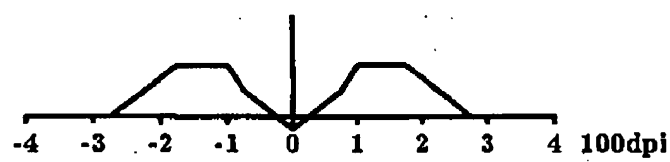

FIG. 5D

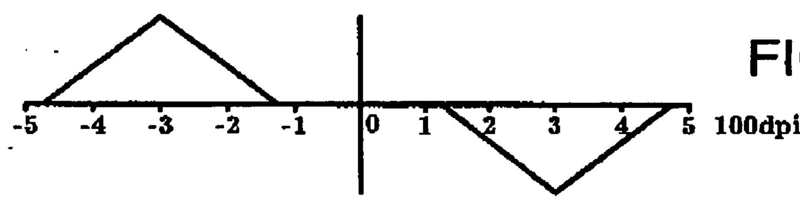

FIG. 5E

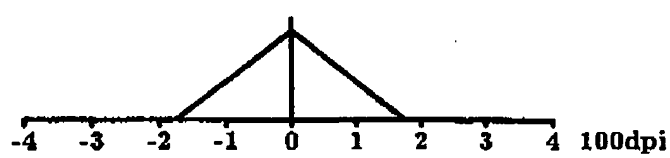

FIG. 5F

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 20 2927

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
D,A	US 5 121 445 A (JUNPEI TSUJIUCHI ET AL.) 9 June 1992 * column 1, line 20 - column 3, line 57 *	1,13	H04N1/40 H04N1/04
A	PATENT ABSTRACTS OF JAPAN vol. 18, no. 570 (E-1623), 31 October 1994 & JP 06 209463 A (G C TECHNOL KK), 26 July 1994 * abstract *		
A	WO 95 27627 A (JOH. ENSCHEDÉ EN ZONEN GRAFISCHE INRICHTING B.V.) 19 October 1995		

TECHNICAL FIELDS SEARCHED (Int.Cl.6)
H04N

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	8 December 1998	De Roeck, A

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